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Method for Operating an Internal Combustion Engine and an Internal Combustion Engine for putting the Method into Practice

Description

The invention relates to a method for operating a piston type internal combustion engine, in particular a reciprocating piston engine, with which each combustion chamber is connected to an inlet duct by means of at least one inlet valve controlled dependent upon the piston movement, with a supercharger discharging into an accumulator and producing a continuous pressure, and an air control valve disposed between the accumulator and each inlet duct which opens and closes with the ignition frequency of the allocated combustion chambers, the air control valve being closeable before the allocated inlet valve, and an internal combustion engine for putting the method into practice.

This type of method is known from the SAE Paper No. 8 51 523 "A NEW TYPE OF MILLER SUPER CHARGING SYSTEM FOR HIGH SPEED ENGINES", where an operating mode is described for charged internal combustion engines with which the supply of compressed charge air either takes place during the whole opening duration of the allocated engine inlet valve, or by phase displacement of the opening times of an additional air control valve incorporated into the inlet duct with respect to the engine inlet valve already before the closure of the engine inlet valve is interrupted. This supply of compressed charge which is advanced with respect to conventional charging during the whole opening duration of the engine inlet valve is referred to in the following as pre-charging for short. This operational mode serves the purpose, according to the aforementioned publication, of variably forming the known Miller method with which expansion cooling of the charge brought into the cylinder is brought about by means of premature closure of the inlet valve.

Charging of engines leads to an increase in power, but on the other hand, problems also occur due to the higher loading of the engine and due to the formation of soot in Diesel engines and pinging [or pinking, knocking] with Otto engines. When using exhaust gas turbochargers, as are predominantly employed nowadays, problems also arise in the low range of revolutions

because the torque is too low, and the engine only responds with considerable delay to changes in load. If one tries to eliminate these faults by means of superchargers, which achieve their optimal operating point with a lower number of revolutions, , an excess supply of supercharger energy is made available at higher numbers of revolutions which energy is released into the atmosphere in the form of accumulated [or backed-up] exhaust gases or excess charge air.

It is therefore an aim when developing internal combustion engines and the object of this invention to achieve improvement in performance, this improvement at the same time being suitable for improving the torque in the low revolution range with engines fitted with exhaust gas turbochargers, and to reduce the risk of pinging [or pinking, knocking] with Otto engines, of soot formation with Diesel engines and of engine loading.

In order to fulfil this objective, the invention is based upon a method of the type specified at the start, the solution of the invention consisting of the features of Claim 1.

In this way, the possibility is created of using the compressed charge air in order to drive the residual gas out of the engine cylinder, wherein a corresponding valve overlap may be provided. At the same time, due to the subsequent expansion of the compressed air to atmospheric pressure, a decrease in temperature is achieved which has an advantageous effect of cooling components and charge. Moreover, the fresh air proportion increases. Finally, by subsequently sucking out uncompressed fresh air after closure of the air control valve, a final charge pressure at the level of atmospheric pressure is reached.

With the known pre-charging without subsequent sucking out of fresh air, it is practically impossible to achieve a specified final charge pressure because the timing of the end of pre-charging would have to be adjusted exactly to the currently given pressure of the compressed charge. By means of the method according to the invention, if atmospheric pressure is not reached, fresh air is

automatically subsequently sucked into the cylinder so that at any time, independently of any losses due to the scavenging process and to changes in the pressure of the compressed charge, it is guaranteed that the final charge pressure corresponds to atmospheric pressure.

An increase in power is therefore achieved by means of the residual gas scavenging, by means of the reduction in temperature, and by means of maintenance of the final charge pressure at the level of atmospheric pressure. At the same time, by using excess waste gas energy an additional advantage is achieved.

If only operation without charging is desired, a relatively small supercharger only acting as a scavenging blower can be used. There is also the possibility, however, of adapting the charging method to the respective operational situation and of bringing about an increase in the final charge pressure by moving the closure time of the air control valve towards the inlet closure of the engine inlet valve. A particularly advantageous embodiment for this consists of the phasing of the opening center of the air control valve being movable dependent upon the desired engine operating mode from phase balance with the opening center of the respectively opening allocated inlet valve in front [or advance] of its opening center. In order, if so required, to be able to also operate the engine with charge, according to a further advantageous embodiment, the opening duration of the air control valve is made changeable, so that in a borderline case, it corresponds maximally to approximately the opening duration of the inlet valve or the inlet valves of each combustion chamber.

According to a further advantageous embodiment, the opening duration of the air control valve can be shortened with increasing phase deviation between the air control valve and the inlet valve in order to convey the concentration of the supply of air from the accumulator to the start of inlet.

A piston type internal combustion engine according to Claim 5 is used to put the method into practice.

Preferably, the device for changing the phasing consists of a computer, the inputs of which are connected to a program memory and sensors for determining operational characteristic values of the engine and/or at least one control component for issuing control commands, and the outlet of which is connected to a positioning device for the air control valve, the program memory according to a particularly advantageous embodiment containing selectable programs. In this way it is possible for the computer to select the charging method corresponding to the optimization target predetermined by the program choice, and taking into account the current operational state of the engine established by the sensors, and which best corresponds to this optimization target taking into account the current control command given by the control component, e.g. the accelerator pedal of a motor vehicle.

Preferably, the sensors are disposed on the combustion chamber and/or the accumulator and are suitable for determining the engine's operational state and pressure and temperature in the accumulator.

Preferably, the inlet side of the supercharger and the duct bypassing it are connected to one another upstream of the valve blocking this duct.

In order to enable the smoothest transition possible between the different charging methods, the phasing can be adjusted with infinite variability by the inlet valve and the air control valve.

The opening duration of the air control valve is preferably changeable, in a borderline case it corresponding maximally to the opening duration of the inlet valve, is as required for conventional charging.

A particularly simple embodiment consists of the duct bypassing the compressor branch containing a directional valve which only allows flow in the

direction of the inlet valve. In this way, atmospheric air is always sucked into the inlet duct when there is negative pressure here.

A controllable valve can, however, also be provided for the duct bypassing the compressor branch which can preferably be blocked dependent upon the position of the air control valve.

With a particularly preferred embodiment, a valve blocking the connection to the duct bypassing the compressor branch is allocated to each inlet duct, in order to limit dead space, the valve allocated to the inlet duct and blocking the connection to the duct bypassing the compressor branch, the allocated air control valve, and the inlet valve or the inlet valves of the allocated compression chambers preferably being disposed closely adjacent to one another.

According to a further advantageous embodiment, the duct bypassing the compressor branch can contain a valve which can be actuated together with the air control valve, wherein both valves may also be combined in a manifold valve.

A particularly advantageous design with the embodiment with the directional valve consists of the manifold valve comprising a rotor enclosed by a valve housing, in the form of a rotation element, and continuously operated dependent upon the engine crank shaft, provided with a connection duct opening towards the housing, successive ports in the direction of circulation for the accumulator and the inlet duct being allocated to the connection duct in the valve housing.

With the embodiment with a controllable valve in the duct bypassing the compressor branch, which is combined with the air control valve to form a manifold valve, an advantageous design consists of the manifold valve comprising a rotor enclosed by a valve housing, in the form of a rotation element, and continuously driven dependent upon the rotation of the engine

crank shaft, provided with a connection duct opening towards the housing, successive ports in the direction of circulation for the accumulator, the inlet duct and the duct bypassing the compressor branch being allocated to the connection duct in the valve housing.

If the air control valve only controls the admittance of compressed charge air into the inlet duct, the end of charging can be influenced by an adjustable closing edge of the port for the accumulator.

With the valve designs with a continuously circulating rotor, a further advantageous embodiment consists of the phasing of the valve opening times being adjustable with respect to the crank shaft by adjustment of the rotor relative to the valve housing.

Another advantageous embodiment using a manifold valve consists of two rotors in the form of rotational elements and continuously operated dependent upon the rotation of the engine crank shaft each being provided with a connection duct and being rotatably mounted in a valve housing, a connection duct in its open position connecting ports for the accumulator and the inlet duct, and the other connection duct in its open position connecting an inlet and an outlet for the duct bypassing the compressor branch, such that the phasing of the rotors with respect to one another can be changed and the phasing of the valve opening times with respect to the engine crank shaft can be changed by adjustment of the rotors relative to the valve housing.

Preferably, the maximum number of revolutions of the rotor or the rotors is determined such that upon two strokes of the allocated engine cylinder or allocated engine cylinders one valve opening is respectively dispensed with.

According to a particularly advantageous embodiment, the number of revolutions of the rotor or the rotors can optionally be gradually halved, by means of which there is the possibility of not charging the engine cylinder during

every working cycle, but to only implement charging in intervals adapted to the power requirement.

With a four-cylinder in-line four-stroke engine a particularly simple embodiment consists of providing three inlet ducts, one inlet duct of which is allocated to the two central cylinders together. By means of this type of embodiment, a control valve, and if appropriate a separate directional valve, can be avoided because on the one hand, from one valve allocated to the two central cylinder together, only relatively short distances are to be covered to both cylinders, and on the other hand, the suction phases of both cylinders do not directly follow one another.

Another advantageous embodiment with a design with a directional valve in the duct bypassing the compressor branch consists of the air control valves having, for at least a number of inlet ducts of an engine, a common, tubular rotor, rotatably mounted in a tubular housing, driven dependent upon the crank shaft rotation, the internal space of which is connected to the accumulator, the inlet ducts opening out, offset to one another, on the housing in the axial direction, a valve opening being allocated to each inlet duct on the rotor, these valve openings being offset corresponding to the ignition sequence in the circumferential direction, and the phasing of the rotor being adjustable relative to the crank shaft. With this embodiment, with which preferably the admittance of compressed charge air to all of the inlet ducts of an engine is controlled by a common rotor, the inner space of the rotor is constantly connected to the accumulator by a single port, thereby providing a particularly simple arrangement. The inlet ducts extending from the housing in the direction of the engine cylinders are each connected separately to the duct bypassing the compressor branch.

The advantages of the method according to the invention can also be achieved if the line [or pipe] for uncompressed charge does not lead into the air inlet duct leading from the supercharger to the combustion chamber, but separate inlet ducts with inlet valves on the combustion chamber, i.e. on the

engine cylinder, are allocated to the compressed charge air and to the uncompressed charge air. An air stroke valve is disposed here in the inlet duct for the compressed charge, whereas a valve is disposed in the inlet duct for the uncompressed charge which closes when there is high pressure on the side of the combustion chamber such that compressed charge supplied to the combustion chamber via the other inlet duct is prevented from escaping. Due to the additional inlet valve on the engine cylinder required with separate inlet ducts, the solution described is however provided with a common inlet duct for uncompressed and compressed charge.

By means of the following description of the examples of embodiments of the invention illustrated in the drawings, this is now described in greater detail.

Fig. 1 shows a schematic illustration of a first example of an embodiment of an internal combustion engine designed according to the invention, of which only one cylinder is shown,

Fig. 2 shows a schematic illustration of another embodiment of an internal combustion engine fitted according to the invention, with the example of a four-cylinder engine,

Fig. 3 shows a schematic illustration similar to **Fig. 2** of a further embodiment of an internal combustion engine fitted according to the invention, with the example of a four-cylinder in-line engine,

Fig. 4 shows a valve arrangement with a directional valve separated from the air control valve for supplying uncompressed charge, shown schematically,

Fig. 5 shows an illustration similar to **Fig. 4** of an embodiment with which the supply of compressed and uncompressed charge is controlled by a common valve,

Fig. 6 shows a variation of the air control valve shown in **Fig. 4,**

Fig. 7 shows a variation of the air control valve shown in **Fig. 5,**

Fig. 8 shows a schematic illustration of changing the phasing of the air control valve shown in **Fig. 5** with respect to the engine crank shaft,

Fig. 9 shows a schematic axial section through another embodiment of an air control valve,

Fig. 10 shows a schematic illustration of the position of the air control valve shown in **Fig. 9** at the time of the opening of the engine inlet valve and when precharging,

Fig. 11 shows the situation at the same time when charging,

Fig. 12 shows a schematic axial section through a further valve arrangement for a four-cylinder engine, and

Fig. 13 shows a sectional view along line XIII-XIIII in **Fig. 12**.

Fig. 1 shows a cylinder 10 of a four-stroke internal combustion engine with a piston 12 which can reciprocate. The cylinder 10 has an inlet valve 14 and an outlet valve 16 to which an exhaust gas line 18 is attached. A turbocharger 20 can be driven by the exhaust gas, and air to be compressed is supplied to said turbocharger by an air filter 22 and a line 24. The air compressed by the turbocharger 20 passes via a line 26 to an accumulator [or storage chamber] 28 which is shown here in combination with a charge air cooler 30. A line 32 leads from the accumulator 28 to an air control valve 34 which is suitable for controlling the admittance of compressed charge air from the accumulator 28 into the inlet duct 36 leading to the inlet valve 14. The inlet duct 36 is connected directly to the air line 24 leading from the air filter 22 to the supercharger 20 via a branch line 40 containing a directional valve 38, the

directional valve, for example a check valve flap ([or non-return valve], being disposed such that a flow bypassing the turbocharger 20 can only take place from the air filter 22 to the inlet duct 36. In order to take into account also engine operational states, in which a supply of suction air is not advantageous, the line 40 can also be fully blocked for the duration of this type of operational state, for which purpose either a separate blocking valve can be provided, or the directional valve 38 can be blocked in the blocking position.

Actuation of the air control valve 34 takes place dependent upon a computer 42 to which a program memory 44 is allocated so that there is the possibility of operating the computer 42 with a program selected from different programs stored for the respective operational conditions. The computer 42 thus processes both automatically supplied information on the operational state of the engine, and also external control commands, as can for example be given in a motor vehicle by the positioning of the accelerator pedal. In the schematic illustration in **Fig. 1**, 46 indicates this type of accelerator pedal which is linked to the computer 42 by a connection 48. 50 indicates a sensor on the engine which is linked to the computer 42 by a connection 52. In this way, the computer 42 can be informed not only of information on the state in the region of the engine combustion chamber, but also for example on the pressure and temperature of the stored charge air.

The computer 42 can be used in order to control the engine operational mode according to different optimization targets, and dependent upon the selection of one or another program from the program memory 44. Dependent upon the information supplied to the computer 42, the computer will thus influence the control timings of the air control valve 34, such that the supply of compressed charge air can either be concentrated on the start of inlet of the engine cylinder 10, also referred to as precharge, or such that the compressed charge air is supplied over the whole opening duration of the inlet valve 14 of the engine cylinder 10, which corresponds to the known charging. With the embodiment shown in **Fig. 1**, the directional valve 38 is closed by the high pressure present in the inlet duct 36 when the air control valve 34 opens, such

that compressed charge air is prevented from escaping. On the other hand, uncompressed air is sucked in via the directional valve 38 when the engine piston 12 with an open inlet valve 14 implements its suction stroke and the air control valve 34 is closed.

In **Fig. 2** it is shown how with a four-cylinder engine, an air control valve 34a, 34b, 34c, and 34d is respectively allocated to each of the four cylinders 10a, 10b, 10c and 10d, in this case the air control valves 34a to 34d being in the form of three-way valves, each of which has two inlets which on the one hand are connected to the line 32 for compressed air coming from the turbocharger 20, and on the other hand are connected to the line 24 for uncompressed air leading to the supercharger 20 via a respective branch line 40a to 40d, and an outlet which is respectively connected to an inlet duct 36a to 36d respectively allocated to a cylinder.

In **Fig. 2**, for simplification of the illustration, the accumulator 28 with the charge air cooler 30 between the turbocharger 20 and the air control valves 34a to 34d was not shown.

Because with the ignition sequence 1-3-4-2 of a four-cylinder in-line engine the working cycles of the two central cylinders 2 and 3 do not directly follow one another, a common air control valve 34e can be allocated to them, as shown in **Fig. 3,** where in particular the distance to the two central cylinders via a common inlet duct 36e is relatively short. Branch lines 40a, 40e and 40d are connected by check valve flaps [or non-return valves] 38a, 38e and 38d. A corresponding connection of the branch lines 40a to 40e can also alternatively be chosen with the design according to **Fig. 2**. The rotor 62 of the valve 34c corresponds to the design shown in **Fig. 7** with two sections 64 and 65.

The embodiment shown according to **Fig. 3** shows a closely adjacent arrangement of the engine inlet valves with respect to the allocated air control valves 34a, 34d and 34e and the check valve flaps 38a, 38d and 38e, by means of which the dead spaces allocated to the individual engine cylinders can be

reduced to a minimum and the accuracy with which the gas exchange can be controlled is improved.

The design shown in **Fig. 1** with a directional valve 38 in a branch line 40 leading directly out into the inlet duct 36 is shown in a somewhat different representation in **Fig. 4**, the function of the air control valve 34 being described in greater detail below. In order to simplify the illustration, the accumulator 28 with the air charge cooler 30 is also left out here between the supercharger 20 and the air control valve 34. With sufficient line volume, the line connection between the supercharger 20 and the air control valve 34 could also serve here as an accumulator.

The air control valve 34 shown in **Fig. 4** has a valve housing 60 in which a rotor 62 circulates, continuously operated dependent upon the rotation of the engine crank shaft. This rotor 62 is in the form of a rotational element and has a sector-like section 64 which with a suitable angular position of the rotor 62 allows a flow between the inlet slit 66 and the outlet slit 68. As can clearly be seen in **Fig. 4**, the connection between the inlet slit 66 and the outlet slit 68 is maintained, while the rotor 62 rotates by approximately 90°. If the rotor 62 is operated with half the number of revolutions of the engine crank shaft, this 90° corresponds to a crank shaft rotation of 180°. With corresponding phasing of the rotor 62 with respect to the engine crank shaft, the connection between the inlet duct 36 and the air compressed by the supercharger 20 during a full suction stroke of the engine piston can be maintained as is required for conventional charging. If the phasing of the rotor 62 is changed with respect to the engine crank shaft with respect to the phasing allocated to the charging such that the rotor 62 runs ahead of the crank shaft, for example such that the opening center of the air control valve 34 coincides with the start of opening of the inlet valve 14, the so-called precharging is brought about with which the supply of air from the supercharger 20 is concentrated on the start of inlet of the inlet valve 14. The air control valve breaks the connection of the inlet duct 36 with the compressed charge air from the supercharger 20 a fairly long time before closure of the inlet valve 14, for example approximately in the middle of

the suction stroke of the piston 12. With the design according to **Figs. 1** and **4**, the negative pressure then present in the inlet duct 36 will open the directional valve 38 so that uncompressed air is taken in via the branch line 40 into the inlet duct 36 and through the inlet valve 14 into the engine cylinder 10 until the inlet valve 14 closes.

Fig. 5 shows a variation with which the branch line 40 is not directly linked into the inlet duct 36, but onto the valve housing 60 by means of a slit 70, and the opening and closing of the branch line 40 is in this way controlled by the rotor 62. The directional valve 38 in the branch line 40 is dispensed with in this design. As one can see from **Fig. 5**, the opening phase of the branch line 40 with respect to the inlet duct 36 is respectively directly after the opening phase for the charge air compressed by the supercharger 20. In the event of charging, during the opening phase of the branch line 40, the inlet valve 14 on the engine is closed again so that only compressed air passes into the cylinder 10.

Fig. 6 shows a variation of the air control valve shown in **Fig. 4** which only has the two ports 66 and 68 for the compressed charge air in the direction going towards the inlet duct 36. Within the valve housing 60 there is in this variation an aperture [or orifice] ring 100 disposed concentrically to the valve housing 60. In the aperture ring 100 a window 104 is allocated to the slit 66 in the housing 60, and a window 108 allocated to the slit 68. The aperture ring 100 can be adjusted by a positioning component 112 which is guided outwards through the slit 114 in the valve housing 60.

The window 104 extends over a sufficiently large angle so that in any position of the aperture ring 100 the opening cross-section of the slit 66 is kept fully open. The window 108 in the aperture ring 100 allocated to the slit 68 is of dimensions such that the edges of the window 108 lying in the direction of circulation of the rotor 62 are suitable to change the position of the closing edge 123 of the slit 68 in the circumferential direction when adjusting the aperture ring 100. By adjusting the aperture ring 100, the opening duration in the region of the slit 68 can therefore be shortened or extended, in **Fig. 6** the position of

the aperture ring 100 corresponding to the charge being shown. By adjusting the aperture ring 100 in the direction opposite circulation of the rotor 62, earlier closure of the valve 34 and so precharging is achieved. The movement of the rotor 62 is adjusted to the movement of the engine crank shaft either by direct actuation of the engine crank shaft or by actuation of the engine cam shaft.

Fig. 7 shows a variation of the air control valve 34 shown in **Fig. 5** with which, unlike the representation in **Fig. 5**, the rotor is also provided with a second section 65. As soon as the rotor has broken the connection between the slit 66 and the slit 68 when the rotor 62 is correspondingly rotated, the section 65 passes into the region of the slit 68 and connects this to the slit 70. Only with phasing of the rotor 62 with respect to the engine crank shaft corresponding to the precharge is the inlet valve 14 of the engine still open at this point in time so that after introducing compressed charge air into the cylinder 10 at the start of the suction stroke of the piston 12, compressed air can then be sucked in from the branch line 40.

Fig. 8 only shows as an example how the phasing of the opening phases of the air control valve 34 can be changed with respect to the crank shaft position of the engine. With the arrangement shown in **Fig. 8**, a position member 94, the length of which can be changed for example hydraulically, is used for this purpose which on the one hand with 96 engages onto a lever 90 actuated dependent upon the engine crank shaft and mounted concentrically to the rotor 62, and on the other hand onto the rotor 62 so that the angular position of the rotor 62 with respect to the lever 90 can be changed. Basically however, there is also the possibility of not adjusting the rotor 62, but of adjusting the valve housing 60 with respect to the rotor 62.

Figs. 9 to **11** show a further variation of the air control valve 34. With this design, two rotors 130 and 132 are disposed coaxially to one another within the valve housing 138, a port 66 leading to the accumulator 28 and a branch 68a of a port 68 leading to the inlet duct 36 being allocated to the in **Fig. 9** upper rotor 130 in the housing 138. A port 70 connected to the branch line 40

and a further branch 68b of the port 68 leading to the inlet duct 36 is allocated to the lower rotor 132 in **Fig. 9**. The rotor 130 is provided with a connection duct 134, and the rotor 132 with a connection duct 136. For better understanding, in **Fig. 9** the ports 66 and 70 on the one hand, and the port 68 on the other hand are shown as being spaced by 180°, whereas, as shown by **Figs. 10** and **11**, these ports are actually offset to one another by approximately 90°. Also for simplification of the illustration, in **Figs. 10** and **11** both rotors 130 and 132 are not disposed coaxially, but are shown purely schematically, offset to one another on the side.

The valve housing 138 is crossed by a drive shaft 140 actuated dependent upon the rotation of the engine crank shaft, and which is enclosed by a hollow shaft 142 connected to the rotor 132, on which in turn a hollow shaft 144 connected to the rotor 130 is disposed such that it can make rotational movements.

In **Fig. 9**, both the drive shaft 140 and the hollow shafts 142 and 144 are guided out of the valve housing 138 towards the upper side, and there are provided with radially extending levers 146, 148 and 150, wherein both the lever 148 and the lever 150 may be adjusted independently of one another with respect to the lever 146 by adjustment components (not shown), in order to change the phasing of the rotors 130 and 132 independently of one another. The arrangement can however also be made such that the lever 148 can be adjusted with respect to the lever 146 and the lever 150 with respect to the lever 148, wherein independent phase adjustment of the two rotors 130 and 132 may also be achieved by corresponding control of the positioning components disposed between the levers. Moreover, the arrangement is made such that as well as the change of the phasing of the two rotors 130 and 132 independently of one another with respect to the drive shaft 140, a combined change of the phasing of both rotors 130 and 132 with respect to the drive shaft 140 is also possible.

In **Fig. 10**, the position of both rotors 130 and 132 at the start of the engine suction stroke at the so-called precharging is shown. It is assumed that the drive shaft 140 circulates with half the number of revolutions of the crank shaft. The connection duct 134 extends over a sector of approximately 105 ° so that in the event of the so-called charging, compressed charge air from the accumulator 28 can be supplied to the engine cylinder during the whole suction stroke.

When the engine inlet valve 14 opens, as shown in **Fig. 10**, the opening edge of the connection duct 134 has already moved out so far over the port 68a that the connection between the port 66 and the port branch 68a is broken after a further rotation of the drive shaft 140 by approximately 50° if the engine piston 12 has run through a little more than half of the suction stroke. Whereas compressed charge air can flow via the connection duct 134 and the inlet duct 36 through the inlet valve 14 and the cylinder 10, the connection between the port 70 and the port branch 68b is closed. This connection is opened with the angular position shown in **Fig. 10** between the rotor 130 and the rotor 132 as soon as the connection between the port 66 and the port branch 68a closes so that following precharging, uncompressed charge air can flow into the engine cylinder 10 until the inlet valve 14 closes.

In **Fig. 11** the drive shaft 140 adopts the same angular position as in **Fig. 10** after here too the time has been reached when the inlet valve 14 opens. The rotor 130 is adjusted with respect to the drive shaft 140 in the direction opposite to circulation such that it now releases the connection between the port 66 and the port branch 68a. The angular position of the rotor 132 with respect to the rotor 130 is also changed so that the connection between the port 70 and the port branch 68b remains broken for as long as the inlet valve 14 is open. The supply of compressed charge air to the so-called charging therefore takes place over the whole suction stroke of the piston 12.

Any intermediate positions can be set at any time.

With the embodiment shown in **Figs. 12** and **13**, the starting point is the non-limiting notion of the situation with a four-cylinder in-line engine, an inlet duct 36a, 36b, 36c and 36d being allocated to each engine inlet valve. The duct 40 bypassing the compressor branch 20, 28, 34 (**Fig. 1**) is respectively connected by a non-return valve 38 to each of the inlet ducts 36a to 36d. In the way already described, an air control valve 34a to 34d is allocated to each of the inlet ducts 36a to 36d in order to make it possible for the compressed charge air from the accumulator 28 to be admitted to the individual engine cylinders corresponding to the ignition sequence and the chosen phasing. With the embodiment shown in **Figs. 12** and **13**, these air control valves 34a to 34d are combined to form a common subassembly with a common rotor 62f which is tubular in form and rotatably mounted in a common housing 60f. The rotor 62f is actuated dependent upon the crank shaft rotation, its phasing with respect to the crank shaft being changeable, however, by means not shown in detail here. The individual inlet ducts 36a to 36d are attached to the housing 60f in the axial direction, offset to one another. In the corresponding axial position are located the valve openings 64a to 64d allocated to the inlet ducts 36a to 36d in the rotor, which are offset in the circumferential direction of the rotor 62f corresponding to the ignition sequence of the engine cylinder. The devices for actuating the rotor 62f and for adjusting its phasing, and the connection of the internal space 160 to the accumulator 28 can be implemented in any way which does not pose any difficulty for an expert in the field, and so are therefore not described in greater detail here.

With the example shown, it is assumed that the rotor 62f is actuated with half the number of revolutions of the crank shaft so that the rotor 62f will implement a full rotation, whereas for example on a four-cylinder in-line engine, the ignition sequence 1-3-4-2 will be run through once. The valve openings 64a, 64c, 64d and 64b pass through a corresponding sequence so as to coincide with the ports of the inlet ducts 36a, 36c, 36d and 36b.

If one reduces the number of revolutions of the rotors 62 or 130 and 132 to a quarter of the number of revolutions of the crank shaft, each combustion

chamber will only be supplied with charge air in every second working cycle so that with a lower power requirement with a constant number of revolutions of the engine, the individual working cycle will run with higher cylinder charging and so with more favourable specific fuel consumption. By further reducing the power requirement, the number of revolutions of the rotors can be halved again.

In order to simplify the illustration, in the preceding description it was referred to compressed or uncompressed charge air. This can however also be charge air mixed with fuel – as is obvious to an expert in the field.

Patent Claims

1. A method for operating a piston-type internal combustion engine, in particular a reciprocating piston engine, with which each combustion chamber is connected to an inlet duct by means of at least one inlet valve controlled dependent upon the piston movement, with a supercharger producing a continuous pressure and supplying an accumulator, and an air control valve disposed between the accumulator and each inlet duct, said air control valve opening and closing dependent upon the ignition frequency of the allocated combustion chambers, the air control valve being closed before the allocated inlet valve, **characterized in that** after the closure of the air control valve with the open inlet valve, uncompressed charge is sucked into the combustion chamber as soon as the pressure in the combustion chamber is below the external pressure.

2. The method according to Claim 1, characterized in that the phasing of the opening center of the air control valve is movable dependent upon the desired engine operating mode from phase balance with the opening center of the respectively opening allocated inlet valve in front of its opening center.

3. The method according to Claim 2, characterized in that the opening duration of the air control valve is changeable.

4. The method according to either of Claims 2 or 3, characterized in that the opening duration of the air control valve is shortened between the air control valve and the inlet valve as the phase deviation increases.

5. A piston-type internal combustion engine, in particular a reciprocating piston engine, for putting the method according to Claim 1 into practice, with at least one combustion chamber which is connected to an inlet duct (36) by means of at least one inlet valve (14), with a supercharger producing a continuous pressure (20), the pressure side of which is connected to an accumulator (28), with an air control valve (34) between the accumulator (28)

and each inlet duct (36), the actuation of which is designed such that it is actuated dependent upon the ignition frequency of the allocated combustion chambers, and that it closes before the allocated inlet valve, characterized in that each combustion chamber can be supplied with uncompressed charge after closure of the air control valve via a duct (40) bypassing a compressor branch comprising the supercharger (20), the accumulator (28) and the air control valve (34) and which can be blocked by a valve (38).

6. The internal combustion engine according to Claim 5, characterized in that each inlet duct (36) is connected to the duct (40) bypassing the compressor branch.

7. The internal combustion engine according to either of Claims 5 or 6, characterized by a device for changing the phasing of the inlet valve (14) and the air control valve (34) by shifting the opening center of the air control valve (34) from phase balance with the opening center of the respectively opening allocated inlet valve (14) in front of its opening center.

8. The internal combustion engine according to Claim 7, characterized in that the device for changing the phasing consists of a computer (42) the inlets (48, 52, 56) of which are connected to a program memory (44) and sensors (50, 54) for determining operational characteristic values of the engine and/or at least one control component for issuing control commands, and the outlet (58) of which is connected to a positioning device for the air control valve (34).

9. The internal combustion engine according to Claim 8, characterized in that the program memory contains selectable programs.

10. The internal combustion engine according to Claim 8, characterized in that the sensors (50, 54) are disposed on the combustion chamber and/or on the accumulator (28), and are suitable for determining the engine operational state and the pressure and temperature in the accumulator (28).

11. The internal combustion engine according to Claim 8, characterized in that the control component is an accelerator pedal (46) of a motor vehicle.

12. The internal combustion chamber according to either of Claims 5 or 6, characterized in that the inlet side (24) of the supercharger (20) and the duct (40) bypassing the latter upstream of the valve (38) blocking this duct (40) are connected to one another.

13. The internal combustion engine according to either of Claims 5 or 6, characterized in that the phasing of the inlet valve (14) and the air control valve (34) is infinitely variable.

14. The internal combustion engine according to either of Claims 5 or 6, characterized in that the opening duration of the air control valve (34) is changeable.

15. The internal combustion engine according to any of Claims 5, 6 or 14, characterized in that the opening duration of the air control valve (34) is adjustable.

16. The internal combustion engine according to any of Claims 5 to 15, characterized in that a charge air cooler (30) is disposed upstream of the air control valve (34).

17. The internal combustion engine according to any of Claims 5 to 16, characterized in that the duct (40) bypassing the compressor branch (20, 28, 34) contains a directional valve (38) which only allows flow in the direction of the inlet valve (14).

18. The internal combustion engine according to any of Claims 5 to 16, characterized in that the duct (40) bypassing the compressor branch (20, 28, 34) can be blocked dependent upon the position of the air control valve (34).

19. The internal combustion engine according to Claim 6, characterized in that a valve (38) blocking the connection to the duct (40) bypassing the compressor branch (20, 28, 34) is allocated to each inlet duct (36).

20. The internal combustion engine according to Claim 19, characterized in that the valve (38a; 38d; 38e) blocking the connection to the duct (40a; 40d; 40e) bypassing the compressor branch (20, 28, 34) allocated to the inlet duct (36a; 36d; 36e), the allocated air control valve (34a; 34d; 34e) and the inlet valve or the inlet valves (14a; 14d; 14b, 14c) of the allocated combustion chambers (10a; 10d; 10b; 10c) are disposed closely adjacent to one another.

21. The internal combustion engine according to any of Claims 18 to 20, characterized in that the duct (40) bypassing the compressor branch (20, 28, 34) contains a valve (62, 70) which can be operated together with the air control valve (62, 66).

22. The internal combustion engine according to any of Claims 18 to 20, characterized in that the valve (62, 70) in the duct (40) bypassing the compressor branch (20, 28, 34) and the air control valve (62, 66) are combined in a manifold valve.

23. The internal combustion engine according to Claims 6 and 22, characterized in that the manifold valve is a three-way valve, the ports (66, 68, 70) of which are connected to the accumulator (28), the inlet duct (36) and the duct (40) bypassing the compressor branch (20, 28, 34).

24. The internal combustion engine according to any of Claims 5 to 16, characterized in that the air control valve comprises a rotor (62) enclosed by a valve housing (60), in the form of a rotational element, and continuously operated dependent upon the rotation of the engine crank shaft, provided with a connection duct (64) opening towards the housing, successive ports (66, 68) in the direction of circulation for the accumulator (28) and the inlet duct (36) being allocated to the connection duct (64) in the valve housing (60).

25. The internal combustion engine according to Claim 23, characterized in that the manifold valve comprises a rotor (62) enclosed by a valve housing (60), in the form of a rotational element, and continuously operated dependent upon the rotation of the engine crank shaft, provided with a connection duct (64) opening towards the housing, successive ports (66, 68, 70) in the direction of circulation for the accumulator (28), the inlet duct (36) and the duct (40) bypassing the compressor branch (20, 28, 34) being allocated to the connection duct (64) in the valve housing.

26. The internal combustion engine according to either of Claims 24 and 25, characterized in that the closing edge (123) of the connection (66, 64, 68) of the accumulator (28) to the inlet duct (36) is adjustable.

27. The internal combustion engine according to any of Claims 24 to 26, characterized in that the phasing of the valve opening times with respect to the crank shaft is changeable by adjusting the rotor (62) relative to the valve housing (60).

28. The internal combustion engine according to Claim 22, characterized in that two rotors (130, 132) in the form of rotation elements and continuously operated dependent upon the rotation of the engine crank shaft are each provided with a connection duct (134, 136) and rotatably mounted in a valve housing (138), a connection duct (134) in its open position connecting ports (66, 68a) for the accumulator (28) and the inlet duct (36), and the other connection duct (136) in its open position connecting an inlet (70) and an outlet (68b) for the duct (40) bypassing the compressor branch (20, 28, 34), such that the phasing of the rotors (130, 142) with respect to one another is changeable, and that the phasing of the valve opening times with respect to the engine crank shaft is changeable by adjusting the rotors (130, 132) relative to the valve housing (138).

29. The internal combustion engine according to any of Claims 23 to 28, characterized in that the number of revolutions of the rotor (62, 130, 132) is determined such that upon two strokes of the allocated engine cylinder or the allocated engine cylinders, one valve opening is respectively eliminated.

30 The internal combustion engine according to Claim 29, characterized in that the number of revolutions of the rotor (62, 130, 132) can optionally be gradually halved.

31. The internal combustion engine according to any of Claims 5 to 30, characterized in that with a four-cylinder in-line four-stroke engine, three inlet ducts (36a, 36b, 36c) are provided, of which one inlet duct (36b) is allocated to the two central cylinders together.

32. The internal combustion engine according to Claim 17, characterized in that the air control valves (34a, 34b, 34c, 34d) of at least a number of inlet ducts (36a, 36b, 36c, 36d) of an engine have a common, tubular rotor, rotatably mounted in a tubular housing (60f), operated dependent upon the crank shaft rotation, the internal space (160) of which is connected to the accumulator (28), such that the inlet ducts (36a, 36b, 36c, 36d) adjoin the housing (60f), offset to one another in the axial direction, such that a valve opening (64a, 64b, 64c, 64d) is allocated to each inlet duct (36a – 36d) on the rotor (62f), these openings (64a-64d) being offset in the circumferential direction corresponding to the ignition sequence, and that the phasing of the rotor (62f) relative to the crank shaft is adjustable.

9 pages of drawings attached